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LIGHT AIRCRAFT SOUND
TRANSMISSION STUDY

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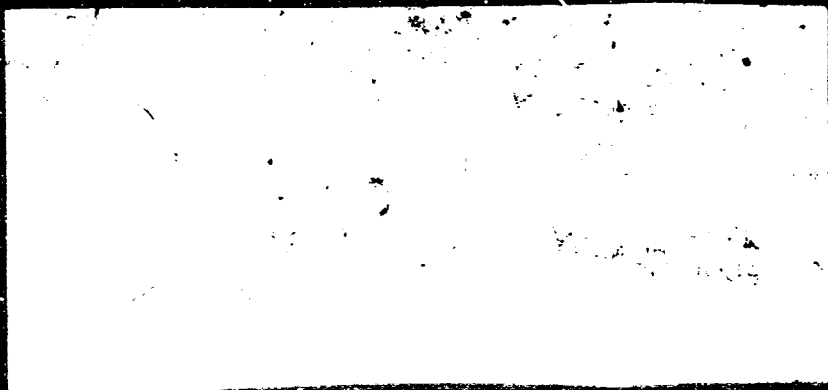NASA
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1. Introduction

The revived interest in the design of propeller-driven air-
craft is based on increasing fuel prices as well as on the need
for bigger short-haul and commuter aircraft. A major problem
encountered with propeller-driven aircraft is propeller and
exhaust noise that is transmitted through the fuselage sidewall
structure. This report presents part of the work which has been
conducted during the period April 1 to August 31, 1983, on the
studies of sound transmission through light aircraft walls.

The fuselage of a small single engine Piper Cherokee air-
craft (Model PA 28-140) was the subject of the tests described in
this report. Earlier work [1] on this fuselage showed that high
frequency noise tends to pass through the plexiglass windows much
more easily than through the aluminum panels with trim, but below
about 400 Hz there appears to be little difference in the
transmission properties of the windows and panels. In order to
reduce the cabin noise significantly, improved sidewall attenua-
tion and absorption within the cabin are expected to be required
in addition to the reduction of source noise levels. In this
study the two microphone sound intensity approach has been used
to identify the major paths of sound energy transmission into the
cabin. Using this sound intensity information the feasibility of
reducing cabin noise by improving the sidewall attenuation by
means of adding mass material to the fuselage and by increasing
the absorption within the cabin has also been studied.

To estimate the noise reduction as a consequence of improved sidewall attenuation or any other treatment, a simple theoretical model is used to predict the sound level differences in the cabin with and without treatment. This model uses acoustic power flows and fuselage structure transmission losses calculated from the sound intensity measurements. The model is based on a simple power balance and predicts the interior sound pressure level from a knowledge of the transmission loss of the fuselage structure and the acoustic absorption within the fuselage.

2. Noise Reduction Results

To evaluate the effect of increased sidewall attenuation treatment, the fuselage under investigation was suspended in a reverberation chamber from three points. A bulkhead made from a 25.4 mm thick sheet of plywood with a 50.8 mm thick sheet of fiberglass attached separated the cabin from the back of the fuselage and all tests were performed with this bulkhead construction in place. The material treatment consisted of attaching a sheet of lead-vinyl (surface density 4 kg/m^2) with the help of double sided carpet tape directly to the exterior parts of the fuselage. Space averaged interior and exterior sound pressure levels were measured with and without sidewall treatment.

Fig. 1 shows the increase in noise reduction as a consequence of covering the whole exterior part of the fuselage with one sheet of lead-vinyl. The increase in noise reduction is between 3 and 5 dB. Addition of one sheet approximately doubles the surface density of the cabin part of the fuselage. Doubling of the surface density should give an increase in noise reduction of about 6 dB. The small discrepancy between the measured and expected increase in noise reduction is possibly due to a less than doubling of surface density and "unblocked" flanking paths. Some potential unblocked paths may include the dashboard and the rear cabin wall. Also the nose and the rear part of the fuselage may experience acoustic excitation causing vibration which may then be transmitted along the aluminum fuselage and result in sound radiated into the cabin.
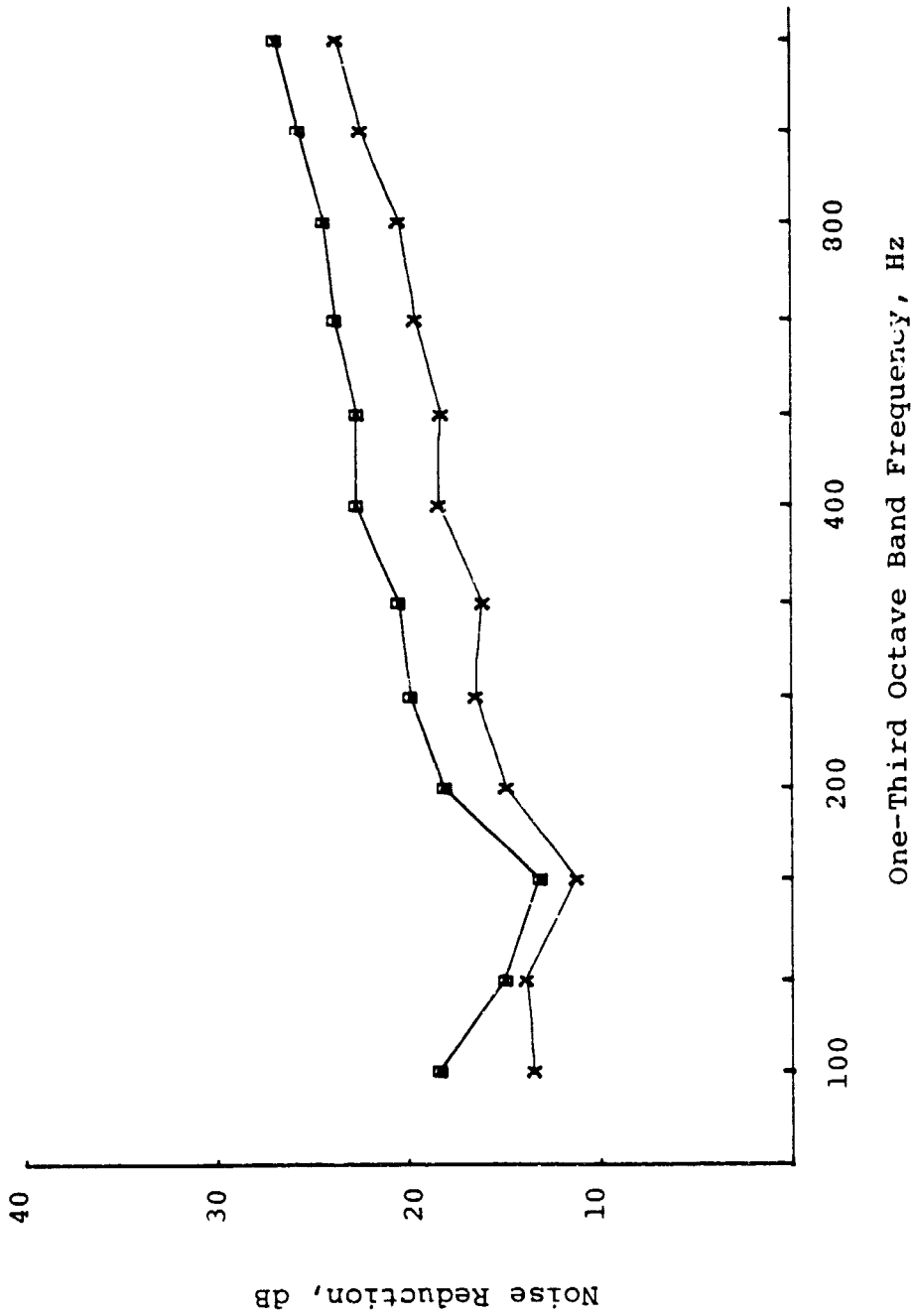
Fig. 1   Effect on Noise Reduction of Covering the Cabin Exterior
With Lead-Vinyl; No Lead Vinyl (x-x-x), One Sheet of
Lead Vinyl (▣-▣-▣).

Fig. 2 shows the effect of increasing the absorption within the cabin. In the present study this was done by adding sheets of fiberglass to the interior of the cabin. This appears to be an effective solution at high frequencies, which unfortunately often play a less crucial role in cabin noise for propeller driven aircraft.

In order to attempt to demonstrate that interior cabin noise can be reduced by treating the dominant sound paths, tests were performed on eight areas of the fuselage sidewall. The eight areas as indicated in Fig. 3 included four single layer plexiglass windows and four aluminum panels with standard trim. All other parts of the cabin fuselage were covered with at least two layers of lead-vinyl. The effect on the noise reduction of covering combinations of these eight areas is shown in Fig. 4.

The addition of one sheet of lead-vinyl to all four aluminum panels has little effect, except in the mid frequency region, where the noise reduction is increased by 2 to 3 dB. At low frequencies the addition of lead-vinyl should have little effect because of its low transmission loss; the effect should be expected to increase with frequency. But at high frequency, as mentioned earlier, the windows are dominant paths of sound transmission and the effect of adding lead-vinyl to the aluminum panels as far as noise reduction is concerned should be very small. These expected effects were fairly well observed in practice as is seen in Fig. 4.
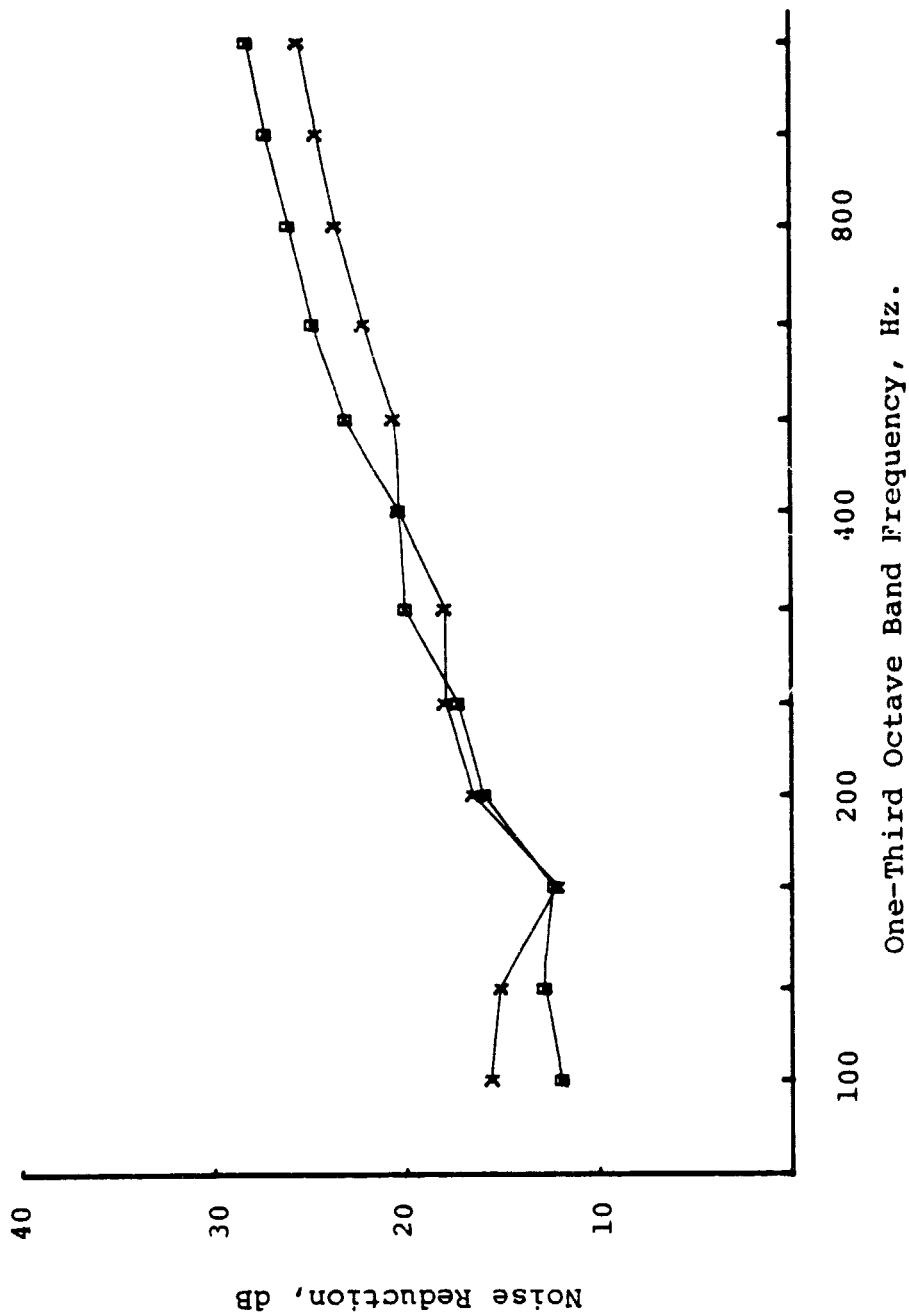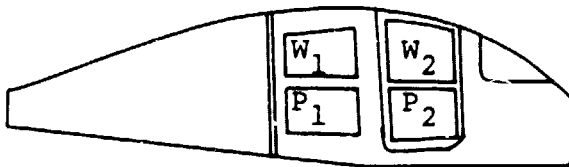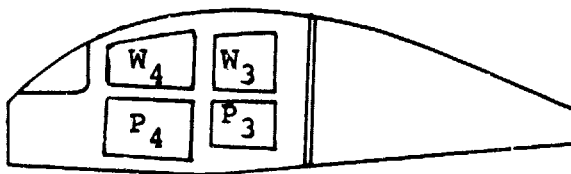
Fig. 2 Effect on Noise Reduction of Placing Sound Absorbing
Material in the Cabin; No Sound Absorbing Material
(x-x-x), Sound Absorbing Material (□-□-□).

Right Side

Fig. 3   Areas of Fuselage Studied in the Experiments.
W_1, W_2, W_3 and W_4 are Plexiglass Windows
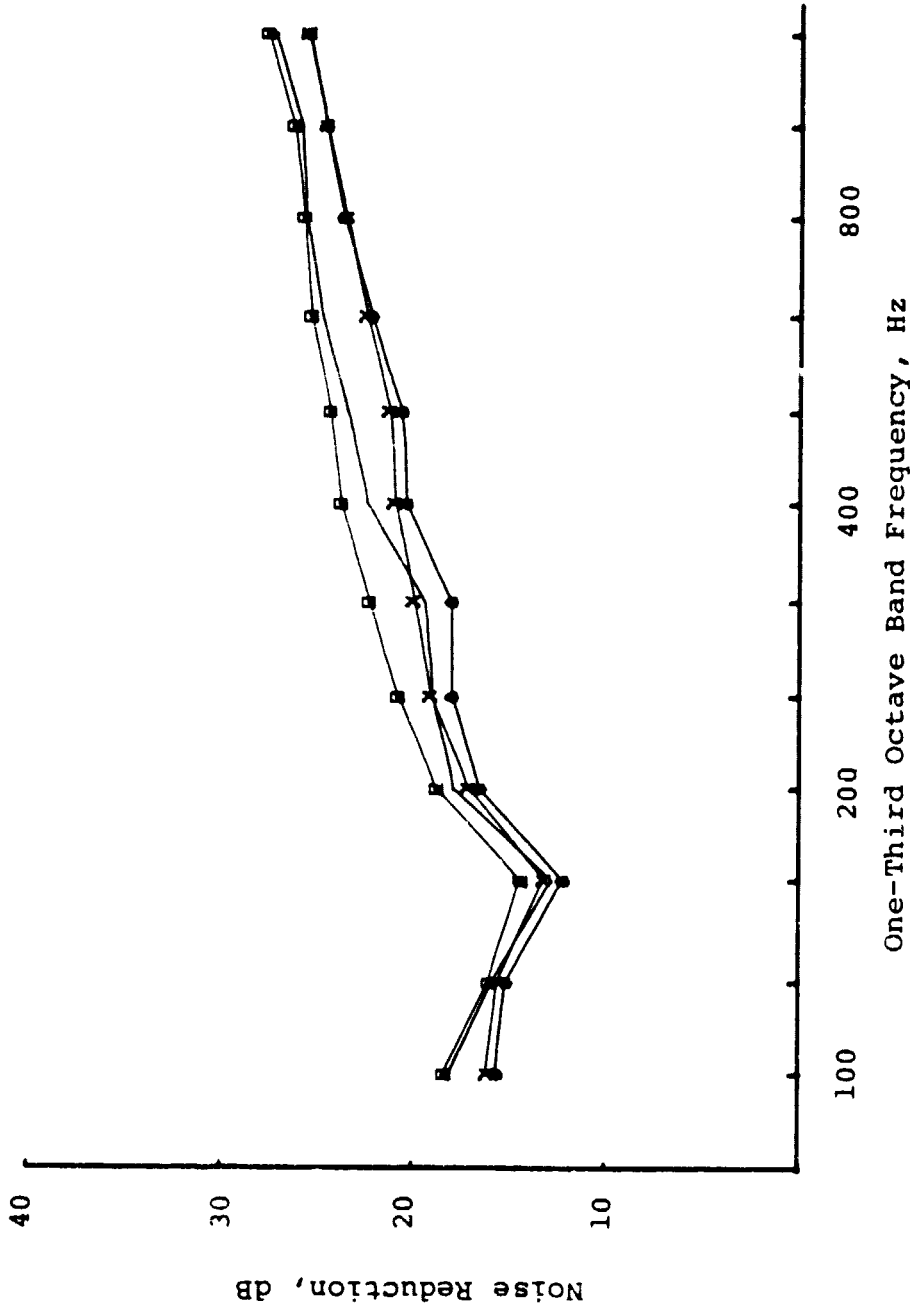and P_1, P_2 P_3 and P_4 are Aluminum Panels With
Standard Trim.

Fig. 4 Effect on Noise Reduction of Placing Lead-Vinyl Over Different Areas of the Fuselage; No Lead-Vinyl Over Any Area (♦-♣-♣), Lead-Vinyl Over P_1, P_2, P_3 and P_4 (x-x-x), Lead Vinyl Over W_1, W_2, W_3 and W_4 (———), Lead-Vinyl Over All Areas Studied (▣-▣-▣).

Addition of one sheet of lead-vinyl to all four plexiglass windows as expected has the effect of increasing the noise reduction. The added noise reduction increases with frequency up to about 800 Hz, with a maximum increase in noise reduction of 5dB. If now all four aluminum panels are also covered, the increase in noise reduction is seen to be substantial at low frequency but is only small at high frequency, due to the fact that at low frequency both aluminum panels and plexiglass windows transmit sound energy almost equally. Hence the effect of covering either panels or windows should be the same at low frequency, but at high frequency the plexiglass windows are the dominant paths and treating these as shown by the results is seen to be more effective.

3. Prediction of Interior Sound Pressure Level

3.1 Theoretical Model

The basic approach followed in predicting the interior cabin sound pressure level is that of making an acoustic power balance. This is achieved by equating the net power flow into the cabin volume to the power dissipated within the cabin volume. An outline of the power flow approach can be obtained from the following generalized equation. For each frequency band, when steady state conditions are reached the power flow can be written as,

$$\sum_i W_i^{in} - \sum_i W_i^{out} = \sum_j W_j^{dis},$$

where W^{in} and W^{out} are the time averaged inflow and outflow power flows respectively, W^{disp} represents power absorption within the cabin volume, i is sub-panel identifier through which the sound power flows and j represents the internal sound power absorption sub-area.

In order to calculate the power inflows and outflows, the exterior sound pressure field and the transmission loss of the fuselage structure sub panels, and the average cabin absorption coefficient ($\bar{\alpha}$) must be known. Thus,

$$\frac{\epsilon_1 c}{4} \sum_i \tau_i S_i - \frac{\epsilon_2 c}{4} \sum_i \tau_i S_i = \frac{\epsilon_2 c}{4} A \bar{\alpha},$$

where ϵ_1 and ϵ_2 are the exterior and interior acoustic energy densities respectively, c is the speed of sound in air, τ_i and S_i

are the transmission coefficient and area of subpanel i respectively, A is the total absorption area of the cabin and $\bar{\alpha}$ is the average absorption coefficient. Thus,

$$N.R = 10\log\frac{\epsilon_1}{\epsilon_2} = 10\log\left\{\frac{\sum_i \tau_i S_i + A\bar{\alpha}}{\sum_i \tau_i S_i}\right\}$$

and since $N.R. = L_{p_{out}} - L_{p_{in}}$,

$$L_{p_{in}} = L_{p_{out}} - 10\log(\sum_i \tau_i S_i + A\bar{\alpha}) + 10\log(\sum_i \tau_i S_i), \qquad (1)$$

where NR is the noise reduction, $L_{p_{in}}$ is the interior cabin sound pressure level and $L_{p_{out}}$ is the exterior sound pressure level. If, however, instead of $\bar{\alpha}$, the reverberation time of the cabin is known, the above equat n c an be written as [2],

$$L_{p_{in}} = L_{p_{out}} + 10\log\left\{\frac{cT_R}{24V\ln(10)}\right\} + 10\log(\sum_i \tau_i S_i), \qquad (2)$$

where V is the volume of the cabin and T_R is the reverberation time of the cabin.

Validation of the interior sound pressure level prediction equation was performed with the airplane suspended in the reverberation chamber and all tests were carried out on eight panels shown in Fig. 3, with at last two sheets of lead-vinyl on all other exterior parts of the cabin. In the analysis it was assumed that sound energy enters the cabin only through the eight

panels, with no leakage through other parts of the fuselage wall.

3.2 Experimental Measurements

3.2.1 Reverberation Time

The reverberation time was measured in one-third octave
bands. The instrumentation for the measurement consisted of a
rotating boom microphone and a sound source inside the cabin, a
Fast Fourier Transform minicomputer (FFT), and a manually
operated relay. The measurement system operates using the inter-
rupted noise method. The relay starts and stops the sound source
and operates the recording of sound decay spectra on the FFT just
before the sound source is turned off. The recorded decay spec-
trum is then stored in the FFT memory, and a new decay spectrum
is taken. The new spectrum is added to the first and the sum is
stored in the memory of the FFT. The process is repeated several
times depending on the accuracy required, each time the new decay
spectrum is added to the sum of the previous decay spectra. The
reverberation time is then determined from the initial slope of
the mean decay spectra. Fig. 5 shows the variation of the cabin
reverberation time with frequency measured using the approach
just described.

3.2.2 Transmission Loss

The transmission loss of the plexiglass windows and aluminum
panels with standard trim was measured using the new two micro-
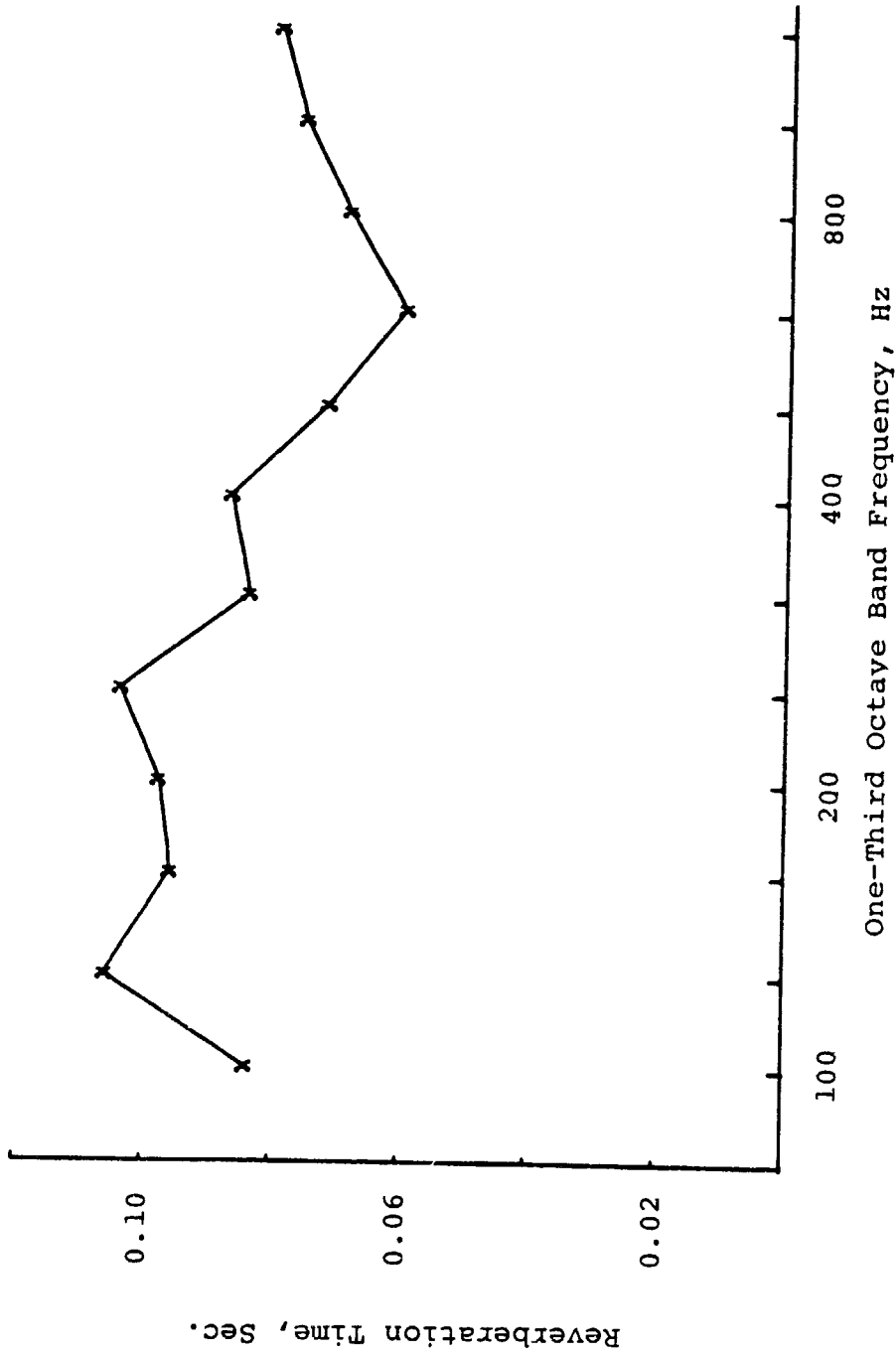phone intensity technique [3,4]. The incident intensity on the

Fig. 5 Reverberation Time Vs. Frequency for the Cabin.

fuselage was assumed to be given by the diffuse field intensity.
The transmitted acoustic intensity was measured by two closely
spaced microphones using two different instruments, namely the
FFT and the B&K real-time intensity analyzer (3360). During the
measurement of transmitted intensity, the interior of the
fuselage was made reasonably anechoic by installing a large
amount of fiberglass within the cabin. Also, to prevent flank-
ing, all other panels but the panel under test were covered with
lead-vinyl. With this set-up the transmission losses of plexi-
glass windows W_1 and W_2 and aluminum panels with trim P_1 and P_2
were measured, with and without one sheet of lead vinyl. From
these measurements, mean values for the transmission loss of
plexiglass and aluminum, with and without lead vinyl were calcu-
lated.

Fig. 6 shows the comparison between the transmission losses
measured using the two instruments. The agreement between the
results using the two instruments is very good. The B&K real
time intensity analyzer has several advantages over the FFT but
it also has one main drawback. On the present B&K analyzer it is
not possible to monitor both sound pressure and sound intensity
at the same time. Monitoring these two quantities can give an
indication of the reliability of the intensity measurement in the
presence of background noise [5].

Figs. 7 and 8, respectively, show the transmission loss of
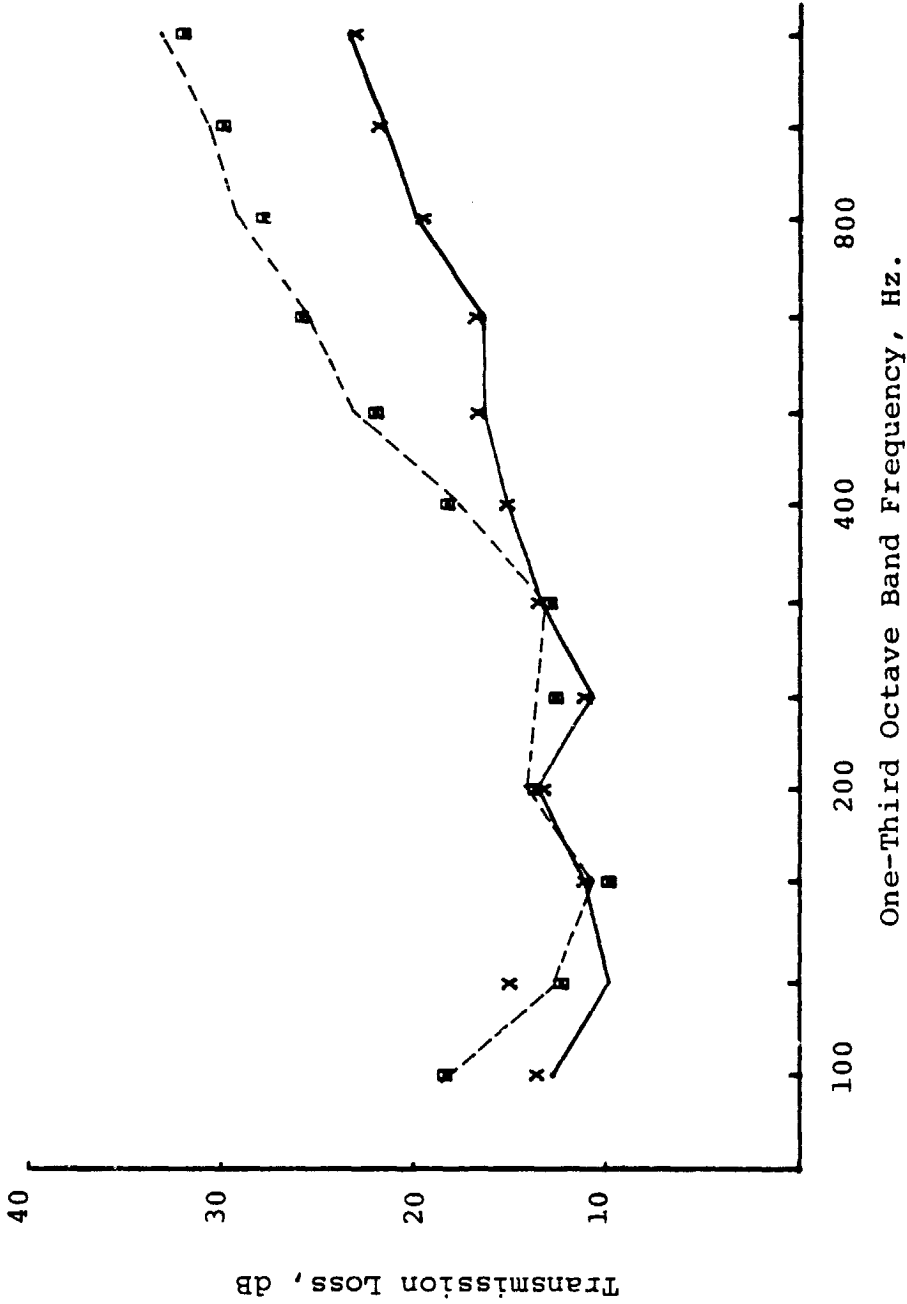plexiglass and aluminum with and without a lead-vinyl layer.

Fig. 6 Comparison Between the Transmission Losses Measured Using the B&K Intensity Analyzer and the FFT; Plexiglass Window Measured with B&K (x), Plexiglass Window Measured with the FFT (———), Aluminum Panel and Trim Measured with B&K (⊡), Aluminum Panel and Trim Measured with FFT (– – –).
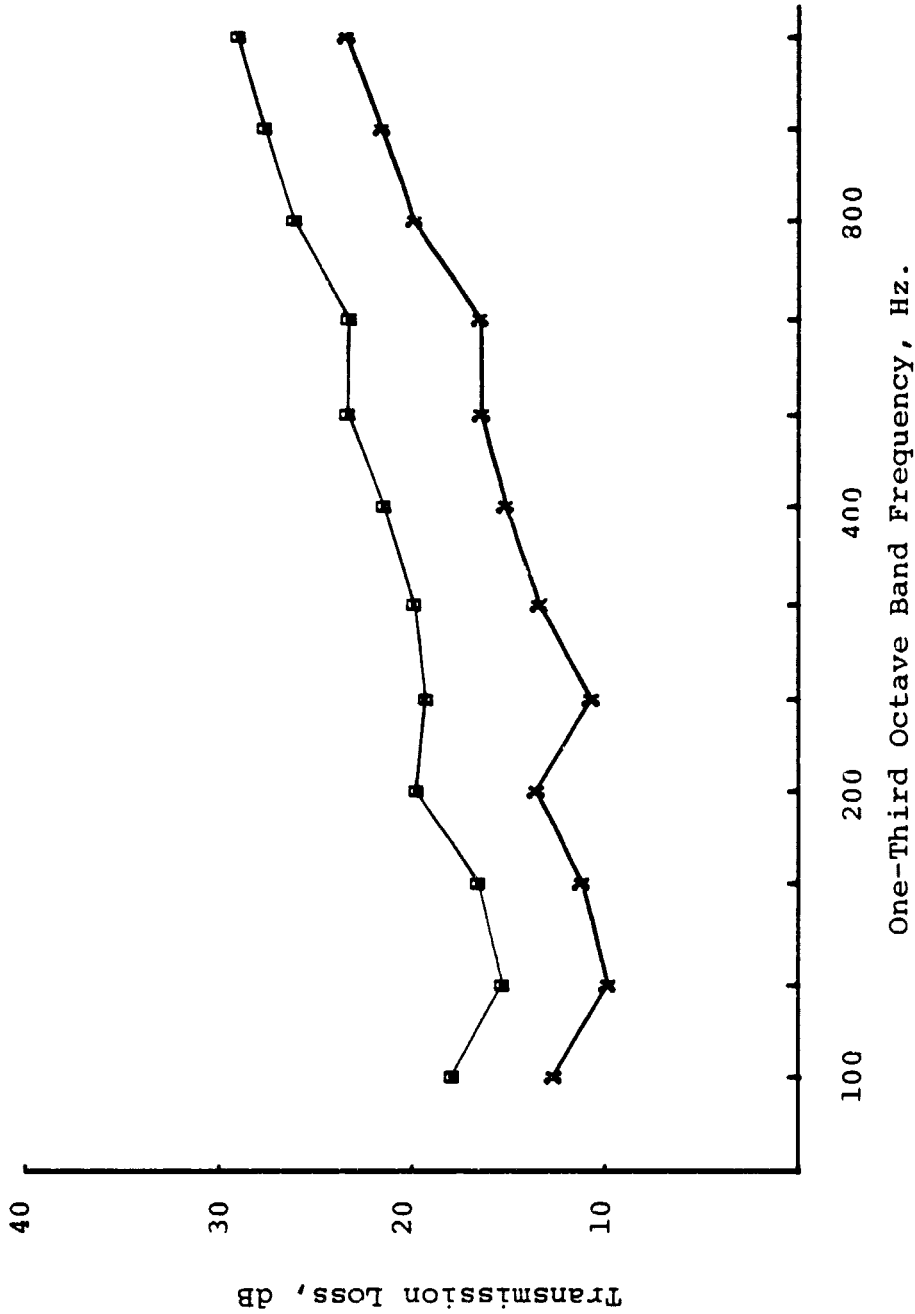
Fig. 7 Transmission Loss Vs. Frequency; Plexiglass Window (x-x-x),
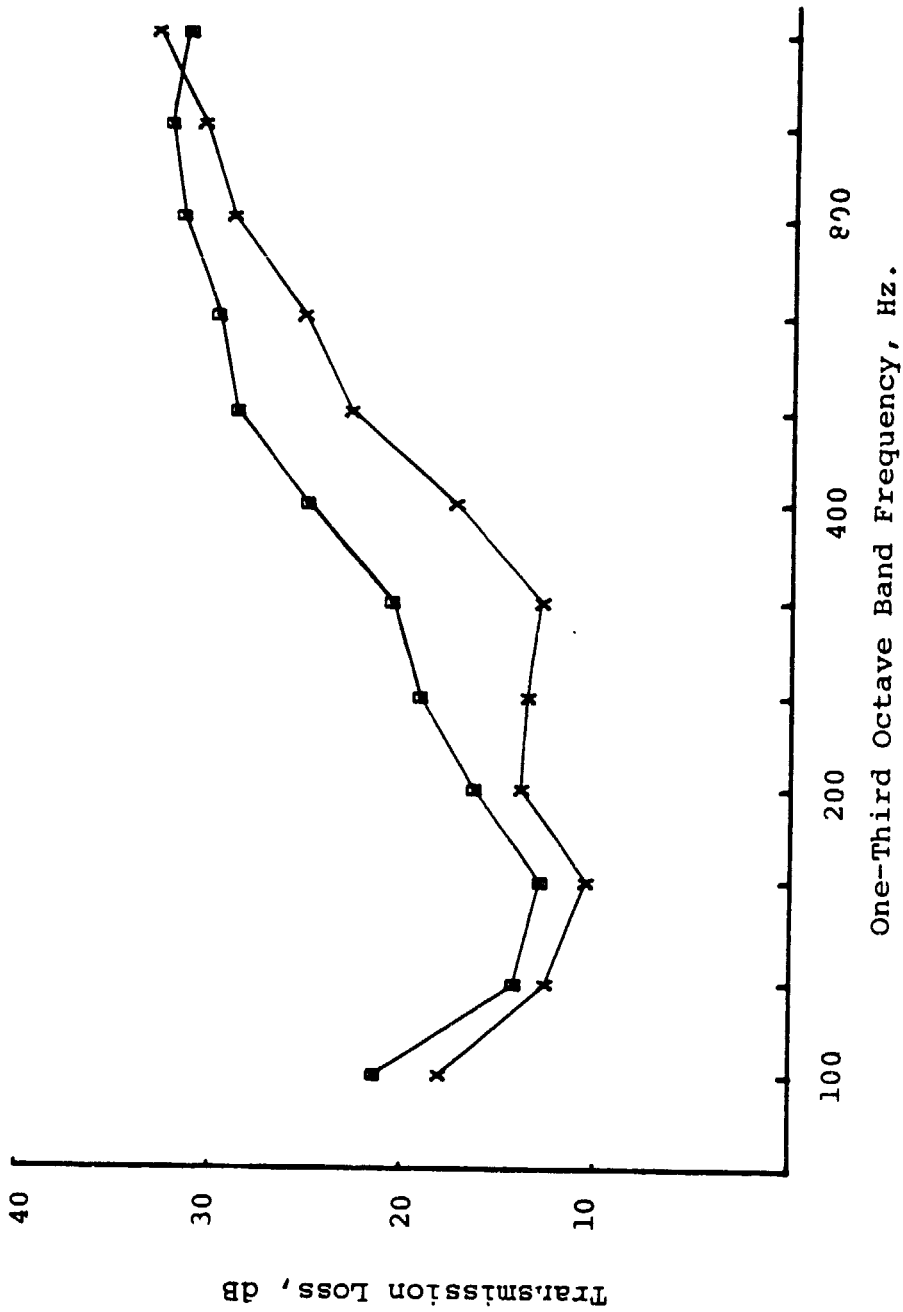Plexiglass Window With One Sheet of Lead-Vinyl (▣-▣-▣).

Fig. 8 Transmission Loss Vs. Frequency; Aluminum Panel With Trim
(x-x-x), Aluminum Panel With Trim and One Sheet of Lead-
Vinyl (□-□-□).

3.3 Comparison of Results

Using the measured values of transmission loss and rever-
beration time, equation 2 was used to predict the interior cabin
space-averaged sound pressure level for three different situa-
tions, namely all 8 areas incovered, 4 windows covered with one
sheet of lead-vinyl, and all 8 areas covered with one sheet of
lead-vinyl. Figs. 9, 10 and 11 show the respective interior
measured and predicted space-averaged sound pressure levels.

In all three cases the predicted and measured results agree
fairly well below 600 Hz, the main frequency region of interest
for such aircraft. The discrepancies in the higher frequency
region are believed to be caused by sound entering the cabin via
"unblocked" paths mentioned earlier, and inaccurate measured
values of reverberation time. Both of these possibilities are
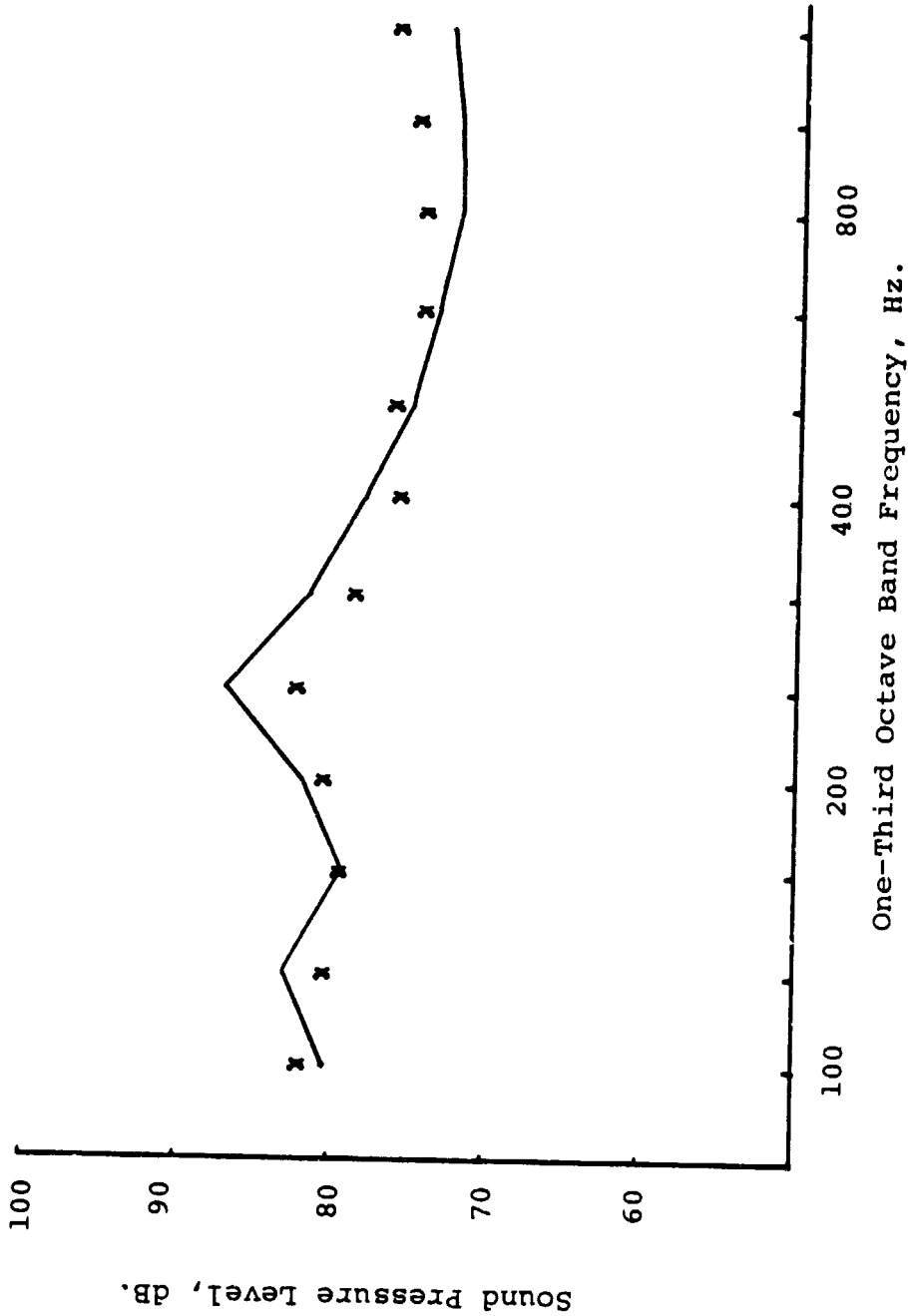being investigated further.

Fig. 9   Comparison of Sound Pressure Level of the Cabin With All
Areas of the Fuselage Under Study Uncovered; Theoretical
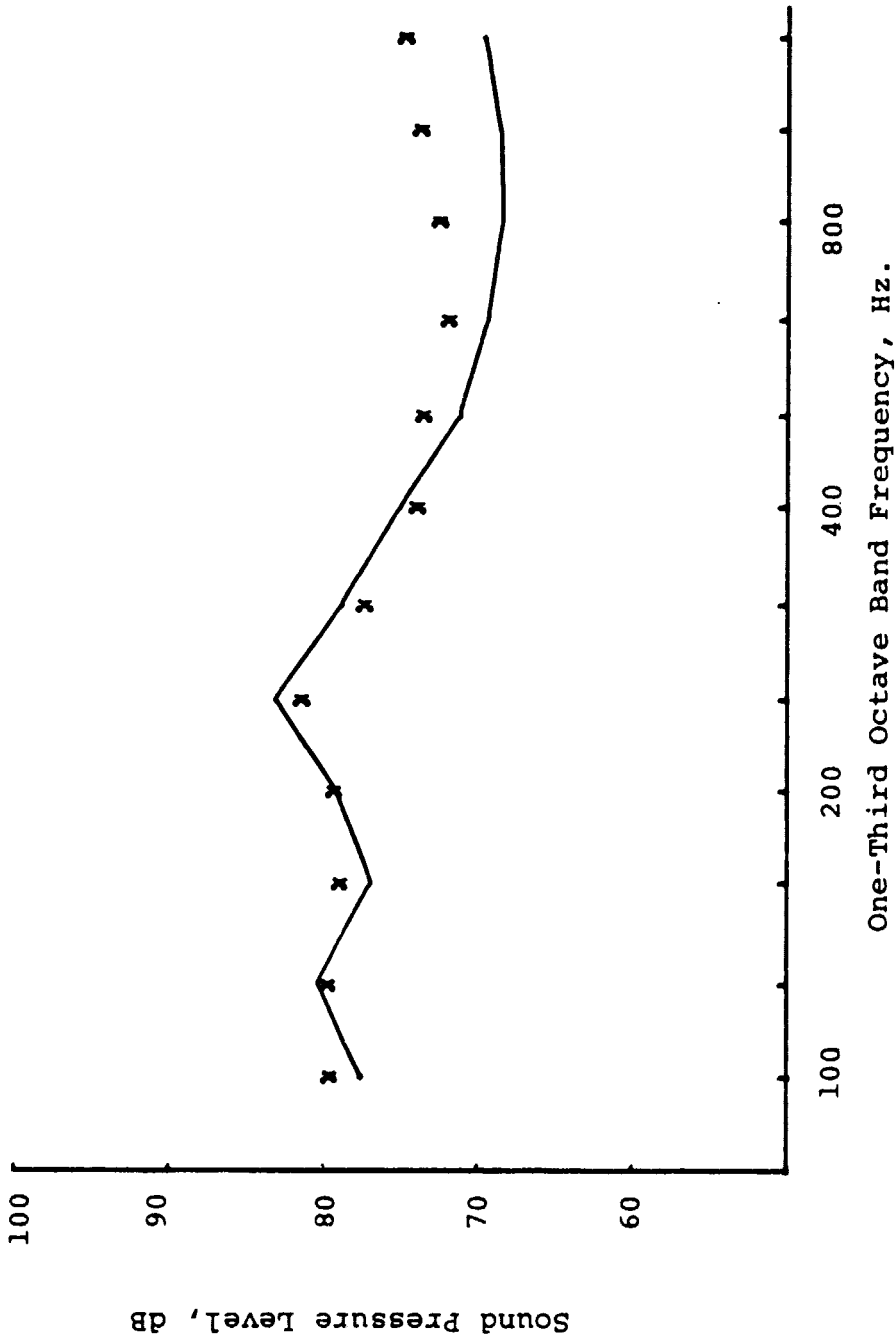Prediction (——————), Measured Results (x).

Fig. 10   Comparison of Sound Pressure Level of the Cabin With W_1, W_2, W_3 and W_4 Covered With One Sheet of Lead-Vinyl; Theoretical Prediction (———), Measured Results (x).
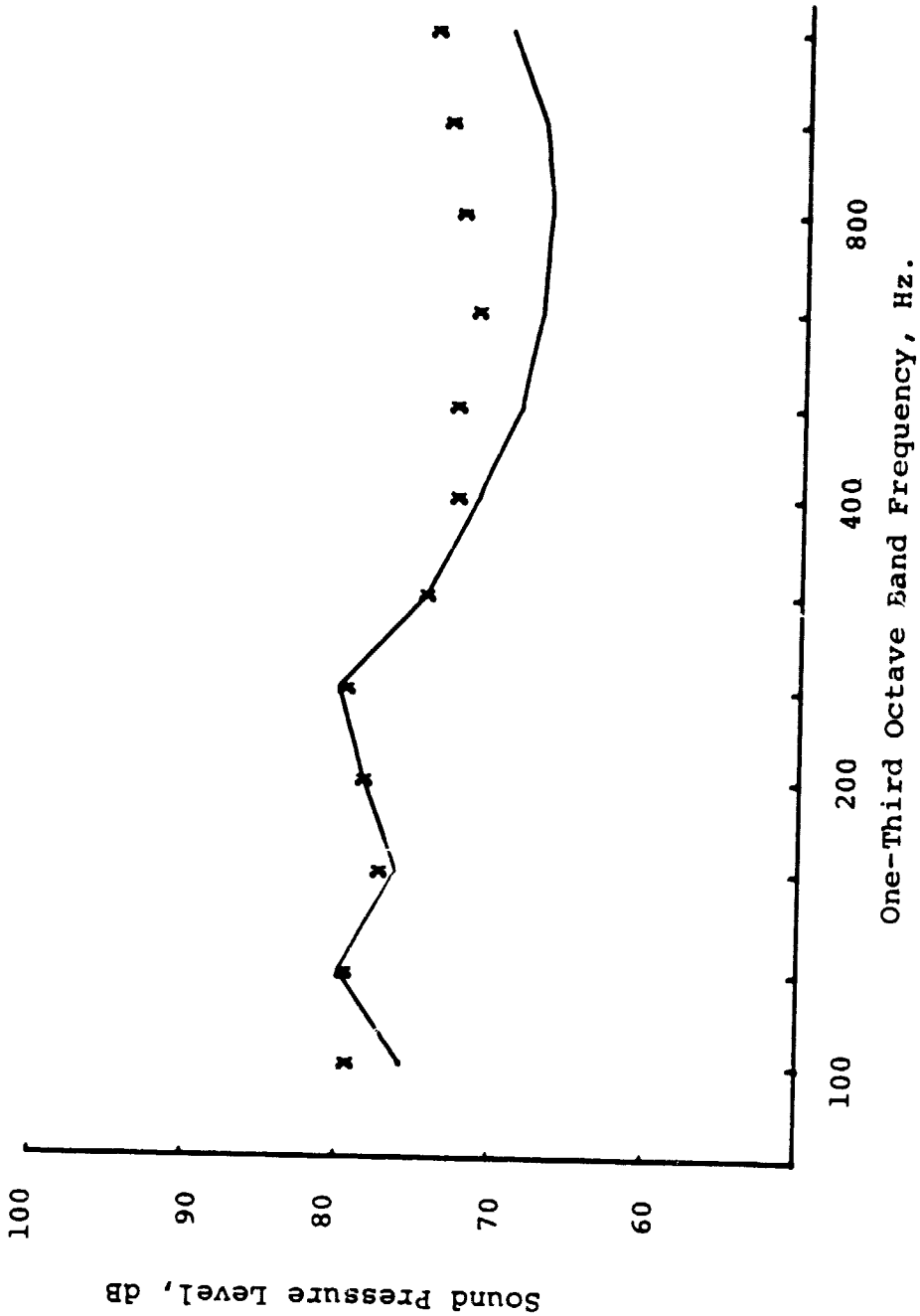
Fig. 11 Comparison of Sound Pressure Level of the Cabin With All Areas of the Fuselage Under Study Covered With One Sheet of Lead-Vinyl; Theoretical Prediction (——), Measured Results (x).

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